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**REMARKS**

Claims 1-10 are all the claims pending in the application. This Amendment adds claims 11-15, and addresses each point of rejection raised by the Examiner. Favorable reconsideration is respectfully requested.

Applicants thank the Examiner for acknowledging the claim for foreign priority under 35 U.S.C. § 119. As explained in a letter filed by the Applicants on February 2, 2004, there was ambiguity on the Office Action cover sheet in this regard. As clarified by the Examiner on February 9, 2004 in a telephone conversation with Applicants' undersigned representative, the foreign priority papers do appear in the USPTO computer system. Accordingly, Applicants request that the Examiner indicate receipt of the these papers in the next action.

**Rejection Under 35 U.S.C. § 102(b) - Claims 1, 4, & 6**

Claim 1, 4, and 6 are rejected under 35 U.S.C. § 102(b) as being clearly anticipated by U.S. Patent 5,113,402 to Itani *et al.* ("Itani").

Itani discloses a laser resonator consisting of a first mirror 1, a Q-switch cell 2, an alexandrite rod 3, a double refraction filter 4, an etalon 5, and a second mirror 5. Fundamental light 6 emitted via the second mirror 5 passes through a non-linear optical crystal 8, creating a second harmonic wave 9. The fundamental 6 and second harmonic 9 then pass through  $\frac{1}{2} \lambda$  plate 10, which makes the planes of polarization of the fundamental 6 and the second harmonic 9 coincident with each other. The fundamental 6 and second harmonic 9 then pass through a second non-linear optical crystal 11, creating a third harmonic 12. The fundamental 6, second

harmonic 9, and third harmonic 12 then pass through a prism 13, whereby the three wavelengths are split up, the third harmonic 12 being directed to an integrator 14 for use as the output.

Applicants respectfully submit that the Examiner has misinterpreted Itani. Specifically, the Q-switch cell 2 is cited as being a semiconductor laser (incorrect under all circumstances), the alexandrite rod 3 and fundamental 6 are cited as being a light wavelength converting element (incorrect under all circumstances), the  $\frac{1}{2} \lambda$  plate 10 is cited as a wavelength plate disposed at a light exiting side of the light wavelength converting element (functionally correct, *if* non-linear optical crystal 8 is used as the light wavelength converting element), and etalon 5 is cited as a removing portion disposed between the wavelength plate and the light wavelength converting element, for removing the fundamental wave from light incident on the removing portion (incorrect under all circumstances).

In more detail, **claim 1** is not anticipated by Itani at least because:

Q-switch cell 2 is not a semiconductor laser from which a fundamental wave exits.

Applicants provide herewith a discussion of Q-switched lasers from Matt Young's *Optics and Lasers* 151-153 (Springer-Verlag 1986). Based on Matt Young's explanation, a Q-Switch cell clearly functions as a shutter between the mirror 1 and the alexandrite rod 3 in Itani.

Alexandrite rod 3 and fundamental wave 6 are not a light wavelength converting element which is optically coupled to the semiconductor laser, and which converts a wavelength of the fundamental wave which has entered from the semiconductor laser. Rather, alexandrite rod 3 is the active component (*i.e.*, laser medium) within the resonator formed between mirrors 1 and 7. It is the alexandrite rod 3 which produces the fundamental (*i.e.*, no converting of the fundamental wave is performed). *See* Itani col. 5, lines 1-8.

Etalon 5 is not a removing portion, disposed between the wavelength plate and the light wavelength converting element, for removing fundamental wave from light incident on the removing portion. Rather, it is an etalon *inside* laser L, and is an element for making the fundamental wavelength to be in a narrow band. *See* Itani col. 5, lines 1-8. In other words, the etalon does not remove the fundamental wave, and is not disposed between the wavelength plate and the wavelength converting element.

Regarding **claims 4 and 6**, Applicants submit that claims 4 and 6 are also not anticipated, at least as a further limitations on claim 1.

**Rejection Under 35 U.S.C. § 103(a) - Claims 2, 3, & 5**

Claims 2, 3, and 5 are rejected under 35 U.S.C. § 103(a) as unpatentable over Itani in view of U.S. Patent 6,327,085 to Osawa *et al.* (“Osawa”).

Regarding **claims 2, 3, and 5**, Applicants submit that the combination of Itani and Osawa fail to overcome the deficiencies of Itani alone, with regard to claim 1.

**Rejection Under 35 U.S.C. § 103(a) - Claims 7-10**

Claims 7-10 are rejected under 35 U.S.C. § 103(a) as unpatentable over Itani in view of U.S. Patent 5,611,946 to Leong *et al.* (“Leong”).

The Examiner states that “with respect to claim 7, Itani discloses the claimed invention except for the shield of <sic> photodiode and the beam splitter from scattered light.”

In addition to the deficiencies of Itani discussed above, Itani does not disclose a photodiode.

Referring to Figs. 2A and 2B, Leong discloses a Q-switched YAG laser 100 outputting a fundamental wavelength; a first non-linear crystal 106 outputting the fundamental and the second harmonic; a second non-linear crystal 109 outputting the fundamental, the second harmonic, and the third or fourth harmonic; a wavelength plate 113 and a polarizer 114 which combine to form attenuator 112; a filter mechanism 116 for selecting the output wavelength; an aperture 120; a beam splitter 121; and a camera adapter 123 including fitting 125 for mounting a camera.

Referring to claim 1, Leong, either alone or in combination with Itani, fails to teach or suggest a removing portion disposed between the wavelength plate and the light wavelength converting element, for removing the fundamental wave from light incident on the removing portion. Specifically, Leong's filter mechanism 116 is *after* the wave plate 113.

Therefore, Applicants respectfully submit that **claims 7-10** are not suggested at least because the combination of Itani and Leong fail to teach or suggest each requirement of the independent claim.

#### **New Claims**

New claims 11-15 are added. Claims 11 and 12 recite a means for controlling an amount of current applied to the semiconductor laser. Claim 13 depends from claim 7 and requires that the photo diode, via the beam splitter, receives light exiting the wavelength plate (the camera in Leong observes whether the laser is striking a surface, rather than receipt of the laser output itself). Claims 14 and 15 further describe the shield. No new matter is included. Entry and consideration are requested.

AMENDMENT UNDER 37 C.F.R. § 1.111  
Appln. No.: 09/972,960

Attorney Docket No.: Q66637

In view of the above, reconsideration and allowance of this application are now believed to be in order, and such actions are hereby solicited. If any points remain in issue which the Examiner feels may be best resolved through a personal or telephone interview, the Examiner is kindly requested to contact the undersigned at the telephone number listed below.

The USPTO is directed and authorized to charge all required fees, except for the Issue Fee and the Publication Fee, to Deposit Account No. 19-4880. Please also credit any overpayments to said Deposit Account.

Respectfully submitted,



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Matt Young

# Optics and Lasers

Including Fibers and Optical Waveguides

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*For my father,  
Professor Arthur K. Young,  
from whom I am  
still learning the art  
of clear thinking*

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where  $W_p$  is the pumping rate per atom,  $W_{21}$  and  $A_{21}$  the stimulated and spontaneous emission rates from level 2 to 1, and  $W_{12}$  the rate of absorption from level 1. Because  $N_3$  is zero, all atoms exist in either level 1 or 2 and  $dN_1/dt$  is just the negative of  $dN_2/dt$ . Because the stimulated-emission and absorption cross sections are equal,

$$W_{12} = W_{21}. \quad (7.15)$$

A steady-state solution to the rate equation is found by setting

$$\frac{dN_2}{dt} = 0, \quad (7.16)$$

from which we find that

$$(W_p + W_{12}) n_1 = (W_{12} + A_{21}) n_2, \quad (7.17)$$

in terms of normalized populations  $n_1$  and  $n_2$ . Using the normalized population inversion  $n$ , we find that

$$n = \frac{W_p - A_{21}}{W_p + A_{21} + 2W_{12}}. \quad (7.18)$$

For amplification,  $n > 0$ , or

$$W_p > A_{21}. \quad (7.19)$$

We must pump to level 2 faster than  $n_2$  is depleted by spontaneous emission.  $W_p$  depends both on the energy density of pump light and on the absorption cross section of the material. Thus, a) an intense pumping source, b) strong absorption of pump light, and c) a long-lived upper level (small  $A_{21}$ ) are desirable, if not necessary.

We estimate the pumping power required to achieve gain by writing  $W_p$  in terms of the photon flux  $F_p$  and cross section  $\sigma_p$  for absorption of pump light,

$$W_p = F_p \sigma_p. \quad (7.20)$$

The pump power per unit area at  $\nu_p$  is  $F_p \cdot h\nu_p$ . Further,  $A_{21}$  is just the reciprocal of the average spontaneous-emission lifetime  $\tau$  of the upper laser level.

Thus,

$$h\nu_p/\sigma_p\tau \quad (7.21)$$

is the required power density incident on the laser. For ruby,  $\sigma_p \sim 10^{-19} \text{ cm}^2$ ,  $\tau \sim 3 \text{ ms}$  and  $h\nu_p \sim 2 \text{ eV}$ . We therefore require about  $10^3 \text{ W cm}^{-2}$  or perhaps  $50$

kW incident at  $\nu_p$  on a rod with total area  $50 \text{ cm}^2$ . The corresponding values for a four-level laser (in which the lower level is not the ground state) may be two orders of magnitude less. Because not all pump frequencies are effective in exciting the laser, the total input power required is greatly in excess of  $50 \text{ kW}$ ; this immediately suggests short-pulse operation with a flashlamp for pumping. The first laser was such a flashlamp-pumped ruby laser, but we temporarily postpone further discussion of such systems.

**Output Power.** We can estimate the total output power emitted by a continuous-wave laser (or the average power emitted by certain lasers that produce irregular outputs). We take ruby as our example. Suppose that the pump power absorbed at  $\nu_p$  is equal to  $P$ . The total output power is approximately

$$P_o = P \cdot \nu_{21}/\nu_p, \quad (7.22)$$

because, in the steady state, each excitation to the pumping level results in a single emission from level 2.

Let us assume that the laser begins to oscillate when the population inversion  $n_2 - n_1$  only slightly exceeds zero. Then, approximately half of the systems will be in the upper level; this condition will persist as long as pumping is continued. Thus, the population  $N_1$  per unit volume of the lower level is about

$$N_1 \cong N_o/2, \quad (7.23)$$

and the total pumping power absorbed is

$$P = (N_o V/2) W_p h\nu_p, \quad (7.24)$$

where  $V$  is the volume of the active medium. Further, we have seen that  $W_p$  is equal to  $A_{21}$  in steady state. Thus, the output power is

$$P_o = (N_o V/2) A_{21} h\nu_{21}. \quad (7.25)$$

A typical ruby rod may be  $10 \text{ cm}$  long with end faces  $1 \text{ cm}^2$  in area.  $V$  is thus  $10 \text{ cm}^3$ , and the other parameters as in the preceding section. Thus, we find  $P_o \sim 10 \text{ kW}$ . This estimate is only slightly high for a system that may emit 1 or 2 joules in a period of 1 ms.

**Q-Switched Laser.** Applications often require high-peak-power (as opposed to high-energy) operation. In a *Q-switched* or *giant-pulse laser*, the laser is prevented from oscillating until  $n$  has been allowed greatly to exceed the usual threshold value  $n_l$ . When  $n$  reaches a very large value, oscillation is allowed to occur, for example, by opening a shutter placed between the laser medium and the total reflector.

The process is detailed in Fig. 7.5. The top curve is drawn as if the reflectance  $R_{eff}$  of one mirror were allowed to vary from a low value to a high value. When

$R_{\text{eff}}$  is small,  $n$  grows large. When the shutter before the mirror is switched open, the power grows rapidly and continues to grow as long as the round-trip gain exceeds 1. The population of the upper level decreases rapidly because of the high energy density. The round-trip gain is just equal to 1 when  $n = n_i$  and falls below 1 thereafter. *Peak power* is emitted, therefore, when  $n$  is just equal to  $n_i$ .

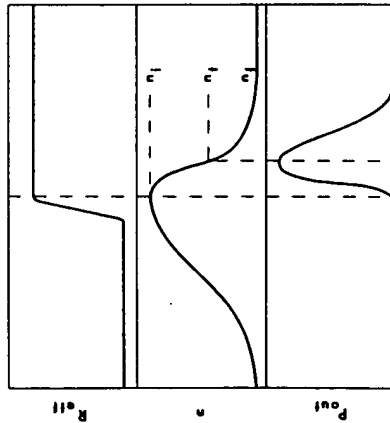


Fig. 7.5. Q-switched laser

Assuming virtually instantaneous switching, we can estimate some of the properties of the output by similar arguments. Suppose the normalized population inversion is  $n_i$  before the shutter is switched and decreases to  $n_t$  at the end of the pulse. Then the total energy emitted during the pulse is

$$E = (1/2)(n_i - n_t) N_0 V \nu_{12}. \quad (7.26)$$

The factor  $1/2$  appears because the population difference changes by 2 units every time a quantum is emitted (because  $n_i$  increases, whereas  $n_t$  decreases after each downward transition). In ruby,  $n_i$  may be 0.2 and  $n_t$ , at most, 0.6 to 0.8. If the pulse is roughly symmetrical,  $n_t$  will be about 0.5. Using these figures for a small ruby rod, we estimate the output energy to be about 5 joules. In fact,  $E$  is more nearly 1 joule for such a laser.

We may estimate the duration of the Q-switched pulse by examining the decay of a pulse in an isolated cavity. Such a pulse oscillates between the mirrors and makes a round trip in time  $t_1 = 2d/c$ . Each time it strikes the output mirror, it loses  $(1 - R)$  of its energy. In unit time, it therefore loses the fraction  $(1 - R)/t_1$  of its energy. The time

$$t_c = t_1/(1 - R) \quad (7.27)$$

is accordingly known as the *cavity lifetime*.

If the population inversion switches rapidly from  $n_i$  to  $n_t$ , we can conjecture that the decay time of the Q-switched pulse is about equal to the cavity lifetime  $t_c$ . Thus, a symmetrical pulse would have a full duration of about  $2t_c$ . If we choose a cavity length of about 50 cm and take  $R \sim 50\%$ , we find that the pulse duration  $2t_c$  is 10 or 15 ns. If anything, the estimate is slightly low.

The peak power can now be estimated. Assuming a nearly triangular shape for the pulse, we find

$$P_m = E/2t_c \quad (7.28)$$

for the case where  $E \sim 1$  joule and  $2t_c \sim 10$  ns, the peak power is of the order of 100 MW.

**Mode-Locked Laser.** We begin by considering a laser oscillating in a large number  $N$  of different wavelengths known as *spectral modes*, all for simplicity taken to have equal amplitudes  $A$ . If we could place a detector inside the cavity at  $x = 0$  and record the electric field  $E(t)$  as a function of time, we would find

$$E(t) = A \sum_{n=0}^{N-1} e^{i(\omega_n t + \delta_n)}, \quad (7.29)$$

where  $\omega_n$  is the angular frequency of the  $n$ th mode and  $\delta_n$  its relative phase. We shall find in the following section that the modes differ in frequency by  $\Delta\omega$ , where

$$\Delta\omega = \omega_n - \omega_{n-1} = 2\pi(c/2d). \quad (7.30)$$

Usually, the modes are not related and the relative phases  $\delta_n$  have different, random values. The modes are incoherent with one another, and the total intensity is found by adding the intensities of the modes; that is,

$$I = NA^2. \quad (7.31)$$

The intensity will have only small fluctuations, which occur whenever two or three modes happen to be precisely in phase.

Suppose we are able to make the modes interact so that they all have the same relative phase  $\delta$ ; that is

$$\delta_n = \delta. \quad (7.32)$$

Such a laser is known as a *mode-locked laser*. The intensity must now be found by adding the electric fields, rather than the intensities,

$$E(t) = A e^{i\delta} \sum_{n=0}^{N-1} e^{i\omega_n t}. \quad (7.33)$$